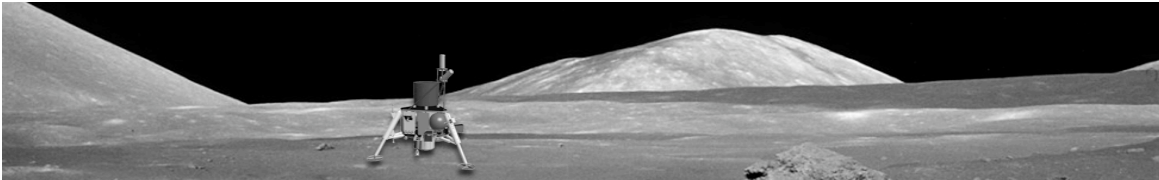
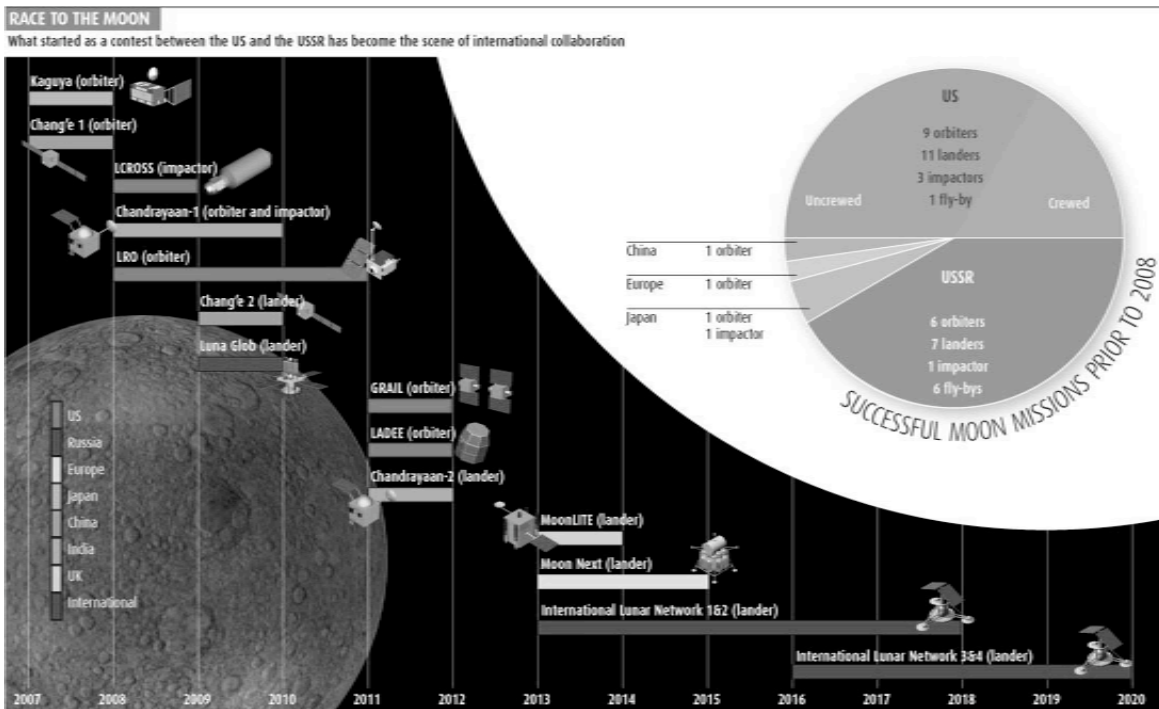


International Lunar Network (ILN) Anchor Nodes

Update to the NAC PSS, 10/03/08
Barbara Cohen, SDT Co-chair
NASA Marshall Space Flight Center
Barbara.A.Cohen@nasa.gov



Robotic lunar missions



D. Mackenzie, New Scientist, July 11 2008

Why the Moon?

The Moon is a witness to 4.5 billion years (Ga) of solar system history, recording that history more completely and more clearly than has any other planetary body. Nowhere else can we see back with such clarity to the time when Earth and the other terrestrial planets were formed and life emerged on Earth.

- ✧ The early history of the Earth-Moon system is uniquely documented and accessible on the Moon.
- ✧ The Moon is the cornerstone to understanding the terrestrial planets (our home).
- ✧ The Moon provides a variety of near-by extraterrestrial environments for science and exploration activities.
- ✧ Exploration of the Moon is an international activity.

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SMD's Lunar Science Program

- ✧ Lunar science flight projects line in SMD's 2009 budget
 - Robotic missions to accomplish key scientific objectives
 - Provide useful data to ESMD and SOMD for returning humans to the Moon
- ✧ Mission 1: **LRO**, which will transition after one year of operations to SMD for a 2-year nominal science mission
- ✧ Mission 2: Lunar Atmosphere and Dust Environment Explorer (**LADEE**), launch in 2011
- ✧ Mission 3: US delivery of two landed payloads as part of the International Lunar Network (**ILN**) – *first US robotic lunar landers since 1968!*
- ✧ These projects provide a robotic lunar flight program for the next decade, complement SMD's lunar R&A initiatives to build a robust lunar science community, and increase international participation in NASA's exploration plans

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Anchor Nodes SDT

- ✧ ILN Anchor Nodes Science Definition Team:
 - Joe Veverka, Cornell, & Barbara Cohen, MSFC, co-chairs
 - Bruce Banerdt, JPL; Andrew Dombard, UIC; Lindy Elkins-Tanton, MIT; Bob Grimm, SWRI; Yosio Nakamura, UT Austin; Clive Neal, UND; Jeff Plescia, APL; Sue Smrekar, JPL; Ben Weiss, MIT
 - Tom Morgan (HQ), John McDougal (ILN Project)
- ✧ The clear focus of the SDT is to address what science is uniquely enabled by the synergy of a network, within the context provided by previous community based activities (SCEM, Tempe, NRESS, etc.)
- ✧ Chartered 03/08; multiple telecons and 1 in-person meeting – charge to the committee, state of the science/instrumentation, formulation and prioritization of science and measurement goals, science baseline and floors
- ✧ Interim report delivered to the Planetary Science Division Director 7/17/08. Final report is being prepared.

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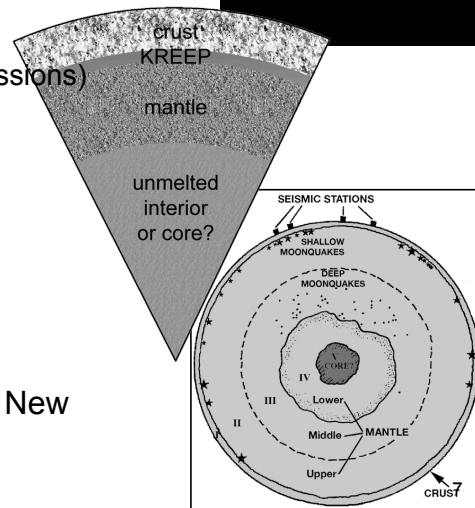
The ILN and the Anchor Nodes

- ✧ The International Lunar Network (ILN) is a cooperative effort designed to coordinate individual lunar landers in a geophysical network on the lunar surface.
 - Each ILN station will fly a core set of instruments requiring broad geographical distribution on the Moon, plus additional passive, active, ISRU, or engineering experiments, as desired by each sponsoring space agency.
 - 24 July 2008: ILN Charter Signing Ceremony formed ILN Landing Site, Communications, and Core Instrument Definition Working Groups.
- ✧ The US is currently planning to provide two ILN nodes (the Anchor Nodes) in 2012-2014 – *this mission*.
 - Anchor Nodes Science Definition Team
 - Engineering Pre-Phase A
 - SMD is also considering a second pair in 2016-17.

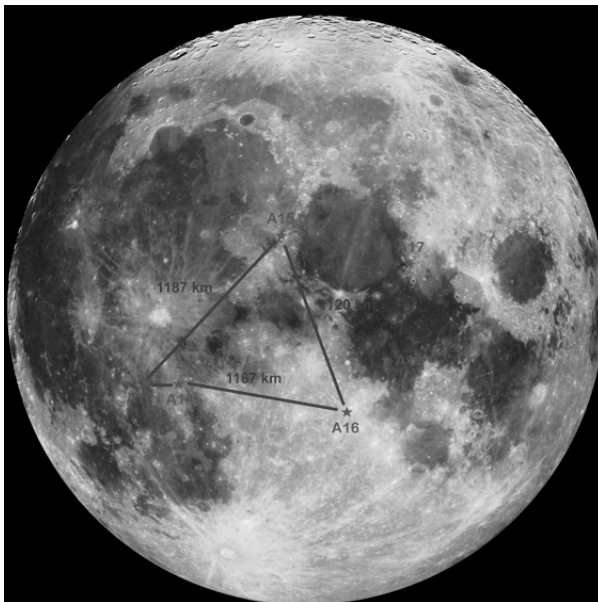
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Geophysical network proposals

- ✧ The Moon is a **differentiated, active, terrestrial** body, preserving a record of early planetary evolution.
- ✧ Several proposals/concepts developed by the science community for small, robotically -deployed geophysical networks:
 - LuSeN, Lunette, etc. (US PI-proposed missions)
 - Mars Netlander / ExoMars (ESA)
 - Lunar-A (JAXA)
 - MoonLite / MoonNEXT (British)
 - Glob (Russia / JAXA)
- ✧ A Lunar Geophysical Network has been recently recommended by the Scientific Context for the Exploration of the Moon (2007), the Tempe meeting (2007), and New Frontiers in the Solar System (2008)



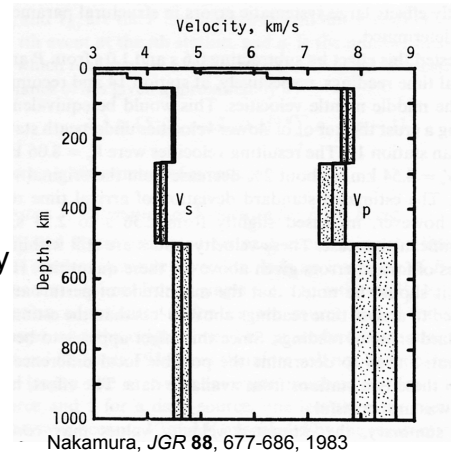
The Apollo seismic network



- ✧ The complete Apollo seismic network (4 nodes) operated from April 22, 1972 to Sept. 30 1977
- ✧ Stations were located ~1000 km apart
- ✧ The next generation of geophysical measurements have to improve on current knowledge by having a wider geographical placement, more sensitive instrumentation, and a longer baseline of observations.

Lunar interior structure: the data

- ✧ Crust on near side is 30-40 km thick; far side is thicker (60 km). It has an anorthositic composition. Lateral variations exist.
- ✧ Crust is broken up (megaregolith) to 10's of km. Vertical and lateral variations probably exist.
- ✧ Lunar Magma Ocean theory says that cumulates formed the crust (flotation) and mantle (sinking), therefore a mantle probably exists.
- ✧ Geochemical arguments hypothesize that the lunar mantle is layered and different composition than Earth's mantle
- ✧ Magmatism was most active > 3 Ga, heat flow in the mantle was higher then.
- ✧ There seems to be a seismic discontinuity at ~500 km on the lunar nearside.
- ✧ There is probably a small (250-350 km diameter) core.



Unresolved science questions

How does a planet differentiate and evolve?

- ✧ Lunar Crust:
 - What are the vertical structural & thickness variations in the lunar crust?
 - Are crustal structure changes gradational or are distinct domains present?
 - What is the global distribution of KREEP?
- ✧ Lunar Mantle
 - How deep was the magma ocean, and how did it evolve?
 - Is there a 500 km discontinuity? Is it structural or compositional?
 - What is the composition of the deep lunar interior?
 - Do crustal boundaries extend into the mantle?
- ✧ Lunar Core:
 - What is the size/composition/state of the lunar core?
- ✧ Moonquakes:
 - What are the locations, depth, and origins of the largest seismic events?
 - What causes deep moonquakes? Are there “nests” on the lunar farside?
 - Are there attenuating (plastic) zones deep within the Moon?

ILN mission objectives

- ✧ The goal of a Lunar Geophysical Network is to understand the interior structure and composition of the moon
- ✧ **Seismometry** is uniquely enabled by a network mission. **Heat flow** measurements, **EM sounding**, and **laser ranging** are highly complementary measurements at each site.
- ✧ The first US mission should provide **anchor nodes** that substantially improve on the Apollo experiments and ensure that first-order science questions will be answered
- ✧ Lunar geophysics \Rightarrow mission objectives \Rightarrow measurement and mission requirements

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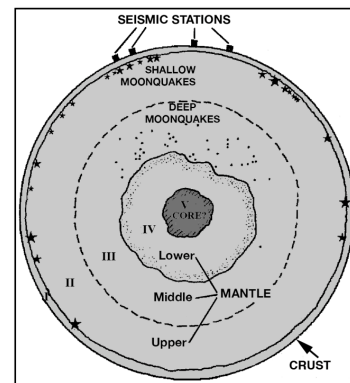
Objective 1: Understand the current seismic state and determine the internal structure of the Moon.

- ✧ Seismic detection of lunar tectonic events will enable determination of the internal structure and composition of a differentiated planetary body. Understanding how strong moonquakes are generated and where they occur has implications for the site of the lunar base.

- ✧ Requirements:

- Three-axis very broad band seismometers
- Multiple nodes simultaneously operating for 1 tidal cycle (6 years)
- Continuous operation (i.e. day and night)
- Global distribution (farside coverage; highland, mare and PKT locations; greater than Apollo's ~1000 km spacing)
- Well-coupled to the surface, thermal and vibrational isolation

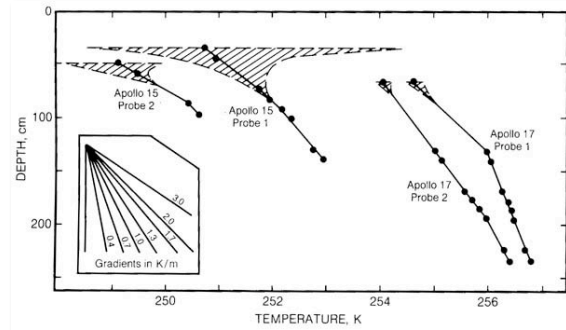
- ✧ Measurement descope options: vibe and thermal insulation, sampling rate



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Objective 2: Measure heat flow to characterize the temperature structure of the lunar interior.

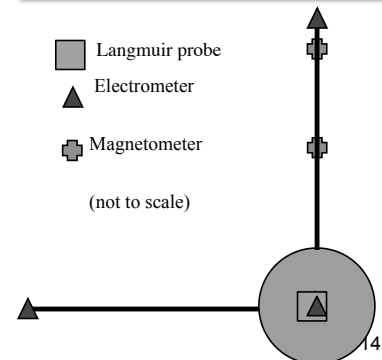
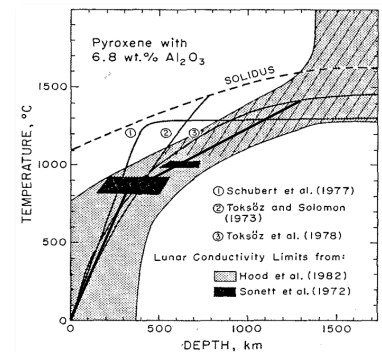
- ✧ Heat flow measurements constrain the abundance of radiogenic elements, lateral variations in crustal and upper mantle composition, and the nature of thermal evolution in a differentiated body.
- ✧ Requirements:
 - Temperature sensor precision: 0.05-0.001 K
 - Array of sensors spaced 30 cm apart to a depth of 3m
 - Good thermal contact of probes to regolith
 - Continuous monitoring every 6-12 hours for 2 years
 - Minimize external thermal variations
- ✧ Measurement descope options: decreased sampling rate, decreased experiment lifetime, decreased number of sensors, shallower depth



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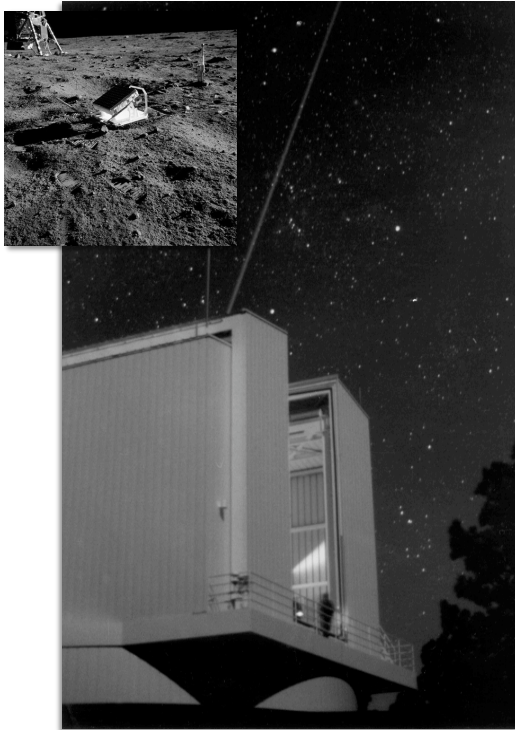
Objective 3: Use electromagnetic sounding to measure the conductivity structure of the lunar interior.

- ✧ Interior temperature and composition can be inferred from conductivity - joint interpretation with seismology and heat flow. Also measures the space-physics environment.
- ✧ Requirements:
 - Three electrometers to measure orthogonal components of electric field up to 100 Hz; two magnetometers to mitigate lander interference
 - Deployment 2m from lander body
 - Langmuir probe to measure surface plasma environment – also of interest to ESMD
 - Continuous operation for 1 year
- ✧ Measurement descope options: Non-continuous data acquisition, shorter data acquisition period, single magnetometer and/or electrometer, decreased boom length



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Objective 4. Determine deep lunar structure by installing next-generation laser ranging capability.



- ✧ Highly accurate laser ranging reveals irregularities in lunar rotation due to tidal changes of the Moon's shape and the effects of internal layering. Ranging also enables tests of gravitational physics and improvement of the lunar orbit.
- ✧ Can also be used to test laser communication systems under development (high bandwidth links) – also of interest to SOMD
- ✧ Requirements:
 - Range accuracy better than 2 cm
 - Passive array, area 10000's of cm^2 (30cm x 30cm), or active transponder

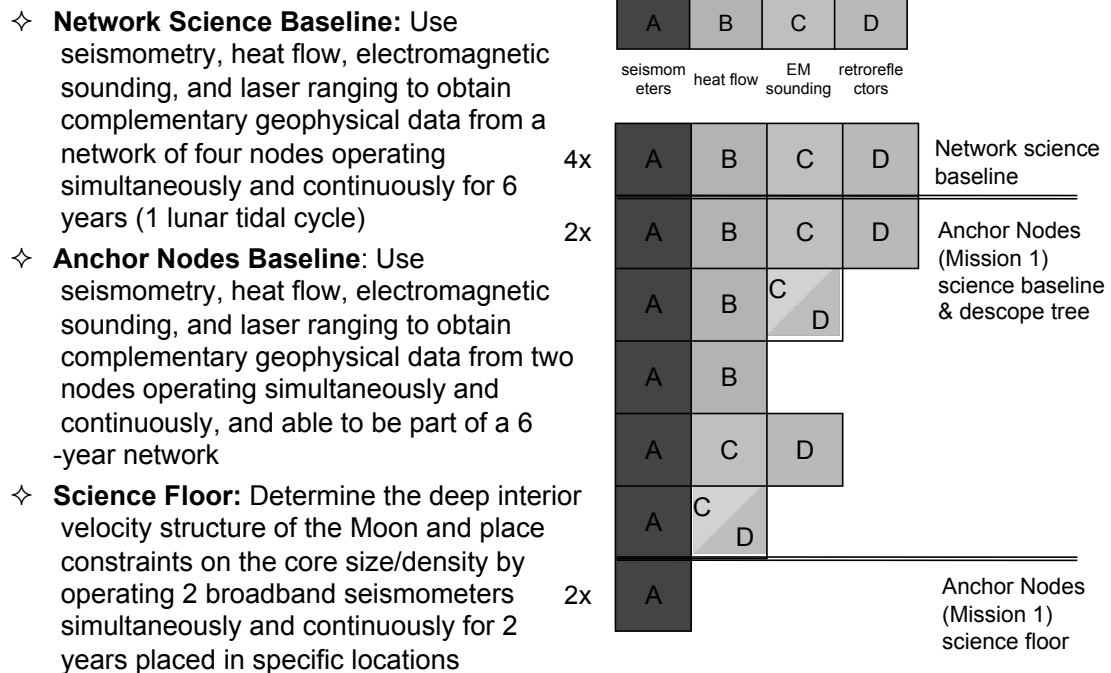
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Other SDT Findings

- ✧ *Operations:* Seismic stations must operate in concert with one another. This requires nodes to be simultaneously and continuously operational.
- ✧ *Number of nodes:* 4 nodes is the minimum number to accurately locate a shallow moonquake anywhere on the lunar surface; 2 is the minimum to investigate the lunar core
- ✧ *Lifetime:* To achieve new science, seismic stations must operate for sufficient time to receive enough signals (6 years for 4 nodes /shallow moonquakes; 2 years for 2 nodes/deep moonquakes)
- ✧ *Location:* If the network begins with one 2-node mission, new science can only be achieved with specific, non-polar site selection.

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Network Science, Baseline, and Floor



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Site Selection Criteria

- ✧ Strong science desire for farside placement for all nodes. Due to dependency upon communications satellite, SDT also identified suitable nearside sites.
- ✧ Node 1 must be placed antipodal to a moonquake epicenter known by the Apollo network: -5°S , 75°W is only nearside site
- ✧ Node 2 must be placed within $\sim 30^{\circ}$ of the same epicenter, so could also be nearside 2: 30°N , 75°E
- ✧ Nodes 3 and 4 should form a triangle with western node, preferably on the farside
- ✧ Site selection criteria will also involve desires from engineering for DV and comm



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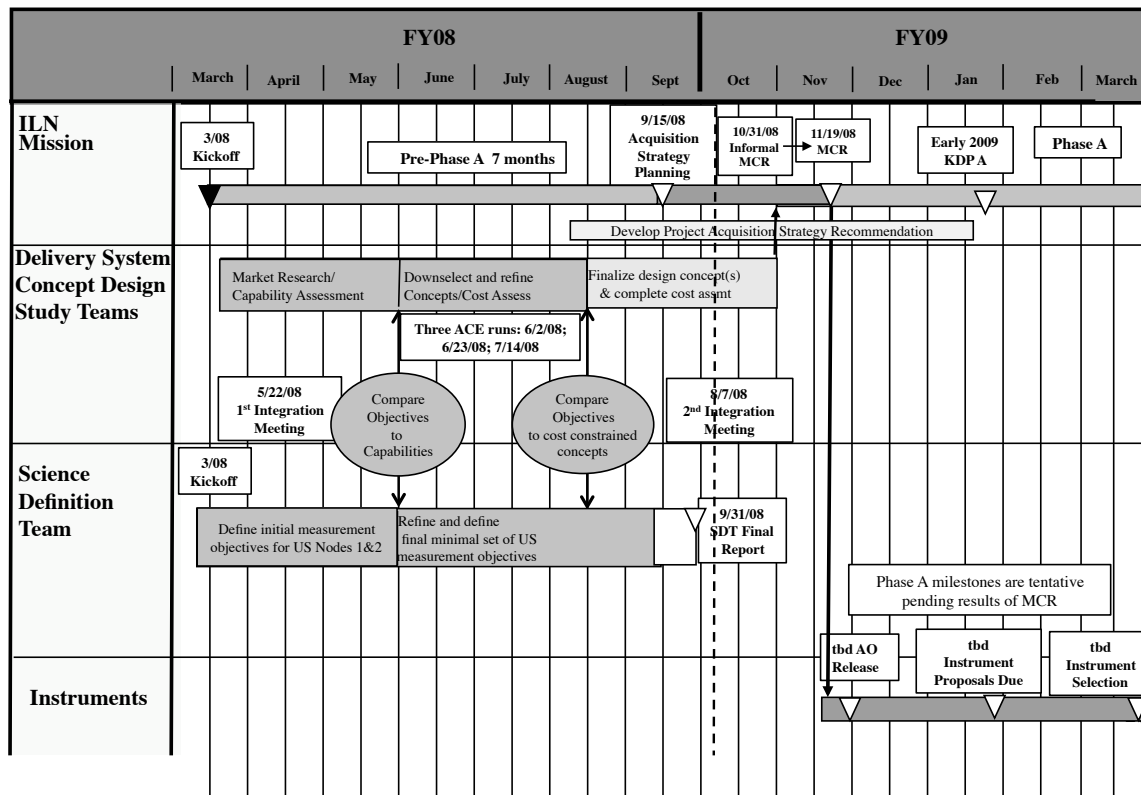
Initial Mission Design Guidelines

Provided by HQ / PSD

- ✧ Develop a mission to emplace two scientific geophysical nodes onto the lunar surface that serve as anchor nodes for the International Lunar Network
- ✧ Launch in 2012 (goal) to 2014 (threshold), depending on resource availability
- ✧ Mission is Category III, Class D
- ✧ Provider: MSFC and APL
- ✧ Instruments
 - Science Definition Team (SDT) has defined floor and baseline science measurements and priorities
 - Instrument selection expected to be completed
- ✧ Mission length: Minimum of 2 years of surface operations
- ✧ Land at “high latitude regions” of the Moon
- ✧ Mission goal of \$200M life cycle cost, including launch vehicle

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Mission Formulation Schedule



Pre-Phase A Highlights

- ✧ Power Subsystem Trade (GRC)
 - Objective: Recommend high-level power system options covering potential locations being considered by the science definition team. Document criteria used to determine viable/nonviable options. Provide results to spacecraft design and integration teams.
 - Result: Derivative ASRG is enabling for minimum lander mass vehicle
- ✧ Inter-center Concept Evaluation Team (ICET)
 - Objective: Identify and assess existing technologies to enable emplacement of multiple lunar surface science instrument packages.
 - Membership: MSFC, APL, ARC, and JPL
 - Traveled to JPL and ARC for site visits, with emphasis on leveraging existing technologies at the sub-system/component level.
 - RFI issued with 18 industry responses. No “new” technologies identified.

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Pre-Phase A Highlights (cont.)

- ✧ MSFC and APL conducted 3 evaluations in the APL Concurrent Engineering (ACE) laboratory. Detailed concept engineering analysis and parametric cost estimates drafted for each case:
 - Floor Science with soft lander and 1 instrument
 - Baseline Science with soft lander and 4 instruments
 - Hard landers and penetrators for baseline and floor science
 - Additional mission concept work to evaluate launching
 - one lander on a Minotaur V,
 - two landers on a Taurus II/Delta II/Falcon 9 and
 - four landers on an Atlas V 401.
 - Additional mission concept/cost estimation work completed to identify options for a \$200M mission
- ✧ ILN technical peer review conducted with members from JPL, Ames, GSFC, GRC, MSFC and APL on August 6
- ✧ Two technical ILN Integration Meetings were held with the SDT and several telecons.

Engineering assessments confirm concept feasibility with multiple solutions to achieve floor and baseline science.

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Summary

- ✧ The International Lunar Network accomplishes high priority science by coordinating landed stations from multiple space agencies
- ✧ The Science Objectives of the network are to understand the interior structure and composition of the moon
- ✧ ILN Anchor Nodes are currently in development by MSFC and APL under the SMD Lunar Science Program
- ✧ Pre-phase A engineering assessments are complete and can achieve science requirements
- ✧ ILN Anchor Nodes will provide the backbone of the network in a way that accomplishes new science and allows other nodes to be flexible contributors to the network

